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INVESTIGATION OF 70-30 COPPER-NICKEL CATAPULT TROUGH HEATER TUBING

Evaluation Test Report No. B-571

25 March 1964

by
D. G. HANSEN

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PLATE NO. 10917

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## ABSTRACT

Aircraft carrier catapult trough heater tubing was tested at the Laboratory to determine the effect of inlet steam temperature on rate of tube wall deterioration. It was found that as long as the catapult trough heater was condensing all the steam that entered at the trough heater tube metal temperature would not exceed saturation temperature. The process involved in tube wall deterioration is erosion. Simulation of shipboard operation in the Laboratory is difficult and costly so further investigations should be made on shipboard. Condensate traps on shipboard should be checked regularly for proper operation.

## SUMMARY PAGE

**The Problem**

The purpose of this test was to determine the effects of inlet steam temperature on the rate of tube wall deterioration in the trough heaters of modern aircraft carrier steam catapults.

**The Findings**

It was determined that the cause of heater deterioration was erosion of the inner surface of the tube wall. This was determined by chemical analysis of tube material collected in the condensate. It was also found that as long as the trough heater is actually condensing steam, the internal tube metal temperature will not exceed the saturation temperature of the steam at the pressure at which the heater is operating. This is the result of desuperheating the steam during its flow through the internal steel tube before contact with the trough heater metal.

**Recommendations**

Operating shipboard trough heater systems should be regularly inspected to be sure that all traps are operating properly and not allowing steam to flow through the heater without condensing. Complete simulation of trough heater operation is not feasible so it is recommended that further investigation of this problem be carried out on shipboard. An alternate method of fin attachment should be investigated

## ADMINISTRATIVE INFORMATION

Testing to investigate the effect of steam temperature on 70-30 copper-Nickel catapult trough heater tubing was authorized by Bureau of Ships letter CVA/9480 Ser 648F-396 of 1 March 1963. The costs of the testing were chargeable to Allotment 211, Project 10, Appropriation SCN2461.

Testing began in June 1963 and was completed in January 1964.

This is a final evaluation test report.

# REPORT OF INVESTIGATION

## Introduction

The steam catapult cylinders of modern aircraft carriers are located in an enclosed trough suspended from the flight deck. To maintain the catapult cylinder at a high enough temperature and thus prevent fluctuations in the length of the catapult during a shot, a trough warm-up system is provided. On USS CONSTELLATION (CVA-64) there are eight individual heaters per trough with a total length of 1050 feet. The material used is 70-30 copper-nickel finned tubing designed to use 600 psi saturated steam as the heating fluid. The source of this steam is downstream of the main catapult desuperheater, and the steam condensed in the heaters is returned to the ships feed system.

The 70-30 copper-nickel tubing has experienced repeated failures in the form of gradual deterioration and loss of wall thickness. The heater drains have become clogged with scale and heater utility has been greatly reduced. Such deterioration calls for frequent renewal of entire trough heating systems at considerable expense.

The purpose of this test was to determine the effects of steam temperature and other variables on the rate of tube deterioration and to determine physical or chemical processes involved in the formation of scale in catapult trough heater systems.

## Description of Material

The catapult trough heater utilizes return flow by the use of two concentric tubes. The steam inlet and condensate drain connections are located on the same end of the heater assembly. The steam is supplied through a 1" IPS seamless steel tube, Military Specification MIL-T-20157 Type "D", having 1.31" OD and 0.120" wall thickness The steam is discharged into the outer tube 12" from the sealed end of the trough heater element. The outer tube is made of 70-30 copper-nickel tubing, Military Specification MIL-T-16420E, Class 1000, Type 1, having 2.375" O.D. and 0.148" wall thickness. The tube is finned with spiral wound copper-nickel fins that are spot welded to the tube. The spacing between inner and outer tubes is maintained by lugs welded to the steel tube. General arrangement and assembly details of the test pieces are presented on Plate 1.

## Method of Test

The test stand used is shown diagramatically in Plate ... Steam at 600 psi was supplied by Laboratory plant boilers. With this system it was possible to obtain steam at temperatures up to 750 F at the test piece inlet. A high pressure cooler was included after the test section to assist in keeping the water before the trap in the liquid state so that flow could be steady. The high pressure cooler also had the effect of simulating an additional section of trough

heater tubing and thus increasing steam flow. A strainer, located at the test piece outlet, and a settling chamber were included in the system to collect products of corrosion or erosion. These products could be blown out while the test piece was in operation and a chemical analysis made. A pressure recorder and a 16-point temperature recorder were used to measure pressures and temperatures at the locations shown on Plate 2.

It was originally planned to operate the test to acquire a total of 340 hours on each of three 20' test sections. Test sections would be exposed to a temperature of 600 F, 700 F, or 500 F and collected residue would be analyzed to determine the cause of deterioration, corrosion or erosion, and if possible, the rate of corrosion. The test was conducted in conjunction with other Laboratory tests since the steam flow to the heater was very small. With the exception of a single 100-hour run, all steaming hours were accumulated on a day to day basis since the Laboratory plant boilers are usually operated only during the regular work day. It was impractical to test more than one section at a time. To prevent oxidation of the test piece during idle periods the test stand was first provided with an 80 psi steam blanket and later with a nitrogen blanket. Periodic inspections were made by removing the test sections from the test stand and chemical analyses were regularly made

of residue collected in the strainer and settling chamber.

Procedure and Results of Tests

Initial operation of Test Piece No. 1 indicated that the test stand was so located and designed that it could not deliver 600 F steam to the test piece regardless of the temperature of the steam at the boiler superheater outlet. This was because the steam flow caused by condensing in the trough heater was so small that the temperature of the steam was reduced as it flowed from the boiler outlet to the trough heater in spite of this line being lagged. This was remedied by the addition of the high pressure cooler which enabled operation with the steam inlet temperature as high as 750 F when the boiler was operating at 900 F.

A total of 340 hours of steam operation at an average temperature of 610 F at the heater inlet were acquired by Test Piece No. 1. Chemical Analyses of residue found in strainer and settling chamber at the times indicated are shown in the table below.

Table 1 - Results of Chemical Analyses
600 F Test Piece

| Date (1963) | Total Hours 600 F Test Piece | Copper in Condensate | Ratio Cu/Ni Settling Chamber | Ratio Cu/Ni Strainer | pH of Condensate |
|---|---|---|---|---|---|
| 28 July | 26.5 | Not Detectable | | | |
| 1[illegible] July | 46.5 | " | 73/27 | | |
| 19 July | 69.5 | " | 66/34 | 61/39 | |
| 16 Aug | 147.5 | " | | | |
| 22 Aug | 174.5 | | | | 7.2(5.9)* |
| 23 Sep | 306 | | | 58/42 | |

* Yard Steam After Extended Steam Blanket.

The following information came to light as a result of chemical analyses.

a. It was determined that copper-nickel tubing was eroding and not corroding. This was so because no copper was found in solution in the condensate and no copper-oxide was present in samples of residue analyzed by x-ray diffraction.

b. Midway in the testing of Test Piece No. 1 it was found that large amounts of iron oxide found coating the inner steel tube and also in the settling chamber were due to the steam used for blanket purposes having a pH of 5.9. It was found that this slightly acid steam was due to sulfite treatment of boilers of Philadelphia Naval Shipyard which provides such steam to the Laboratory. Laboratory plant boilers provided steam with a pH of 7.2. It was thus decided that Test Piece No. 2 would use a nitrogen blanket to prevent this condition.

c. Ratios of copper to nickel generally paralleled ratios of the original material.

d. An analysis was made of scale taken from a trough heater of No. 3 catapult of USS CONSTELLATION CVA-64. This sample had the following chemical analysis. 84% copper and 5.7% nickel. Analysis by X-ray diffraction showed that both copper and cuprous

oxide ($Cu_2O$) were present and that the nickel was in oxide (NiO) form. Traces of $Fe_3O_4$, $Mn_2O_3$ and NiB were also present. This analysis shows that both copper and nickel are being oxidized. This is counter to results of tests made at the Laboratory which determined the cause of deterioration to be erosion. The explanation of this put forward by chemists at the Laboratory is that initial tube deterioration on shipboard is still by erosion but when the eroded residue is on the stagnant recesses of the drain connection of the trough heater, the copper and nickel are changed as a result of chemical reactions.

It was also noted during a visual inspection of the test piece that the inner surface of tube was corrugated conforming to the lead of the wound fins. It was determined that wall thickness was unchanged and that corrugations also were present on the external surface of the tube. Also approximately 70% of all spotwelds holding the fins to the tube had failed after 340 hours and that the remainder were holding only with a small portion of the weld. This corrugation will be discussed later in this report.

Temperature recordings taken when inlet steam temperature was 600 F and condensate temperature was 485 F (saturation temperature) indicated that tube metal temperature never exceeded 480 F.

Test Piece No. 2 was operated at 700 F inlet steam temperature for a total of 150 hours. The results of chemical analyses are tabulated below.

Table 2 - Results of Chemical Analyses
700 F Test Piece

| Date (1963) | Total Hours | Ratio Cu/Ni Settling Chamber | Ratio Cu/Ni Strainer | pH of Condensate |
|---|---|---|---|---|
| 1 Nov | 33 | | | 9.0 |
| 13 Nov | 47.5 | | | 9.1 |
| 3 Dec | 72.5 | | | 9.5 |
| 18 Dec | 110 | 63/37 | 66/34 | |

Ratios of copper to nickel followed the pattern of the 600 F test piece, but high pH readings were encountered in analyses of condensate. It was determined that the boiler was not carrying over and that there were no leaks in the high pressure cooler. Since nitrogen was now being used instead of steam for blanket purposes, this possibility was eliminated. It was finally found that ammonia ($NH_3$) locked in the plant boiler feed system was causing the high pH readings. In view of the Laboratory's difficulty in simulating shipboard conditions (pH of steam = 7.0 $\pm$ .2) it was decided that little could be gained by continuation of the test.

Temperature recordings while operating with inlet steam at 700 F again indicated that all tube metal temperatures were essentially saturation temperature (485 F) as long as condensing was actually taking place in the trough heater element. With the boiler operating

at 850 F at superheater outlet it was possible to raise the inlet temperature as high as 750 F by operating the trough heater element non-condensing. The steam temperature at heater outlet was 550 F and the tube metal temperatures recorded varied between 525 F and 560 F. Temperature of tube metal is unaffected by inlet steam temperature if the tube operates condensing since the steam is desuperheated while passing through the length of the inner tube

Discussion and Conclusions

It is apparent from condensing operation of the trough heater that the internal surface of the tube will not be subjected to temperatures in excess of the saturation temperature at the operation pressure of the heater. If, however, the heater is allowed to operate non-condensing, as it would because of trap malfunction, steam temperature in excess of saturation temperature would be experienced by the heater. The effects of such operation on the rate of tube wall deterioration could not be determined using the present test stand, nor is it necessary since it has been demonstrated that inlet steam temperature has no effect on internal tube metal temperature when the heater is being properly operated.

The actual cause of deterioration has been determined as erosion. This is true for test pieces and, though chemical analysis of scale taken from shipboard trough heaters contains oxides of copper and nickel

it is suspected that the same is true of shipboard heaters. Presence of oxides is probably due to chemical reactions that take place after eroded material is deposited in stagnant clean-out areas of heaters where some undetermined chemical reactions take place.

Inspection of an unused test section revealed corrugations of the tube wall indicating that these result from the manufacturing process. It appears that sections that were tested have corrugations that are slightly greater than the unused sections, though it is possible that this variation could be the result of the manufacturing process also. These corrugations could cause greater turbulence and accelerate erosion but this cannot be stated as a fact since steam velocity in the heater is considered quite low.

## Recommendations

Operating shipboard trough heater systems should be regularly inspected to ensure that traps are operating properly and not allowing steam to flow through the heater uncondensed.

The magnitude of complete simulation of the shipboard arrangement prevented accomplishment in the Laboratory. This was especially true in the simulation of steam flow, steam pH and heater environment. It is recommended that any further investigation of this problem be accomplished on shipboard.

It is also recommended that an improved means of fin attachment be investigated in view of the inability of spot welds to keep the bond between the fin and heater tube. When the welds are broken the fin is contributing nothing to the heat transfer capacity of the heater.

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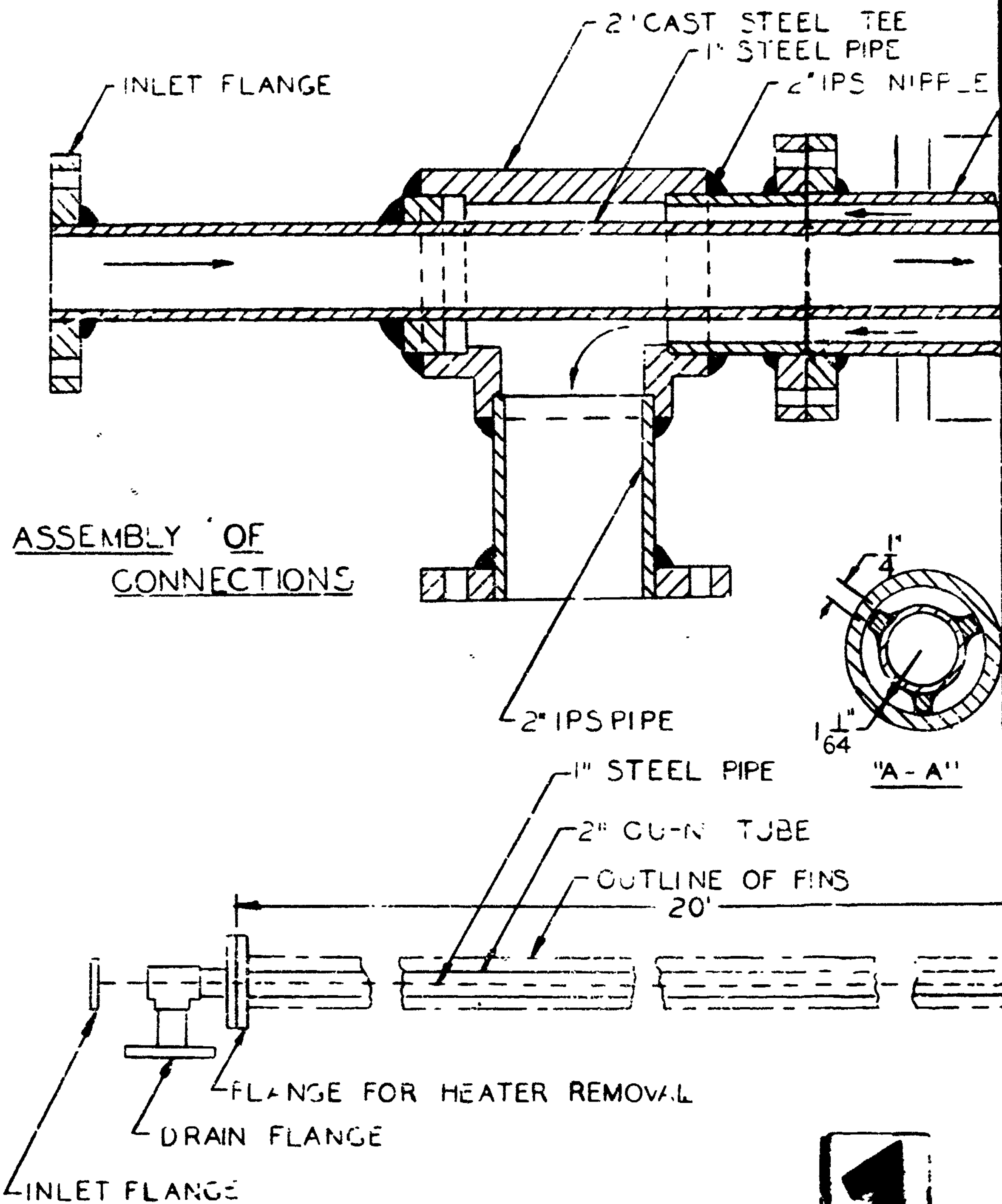
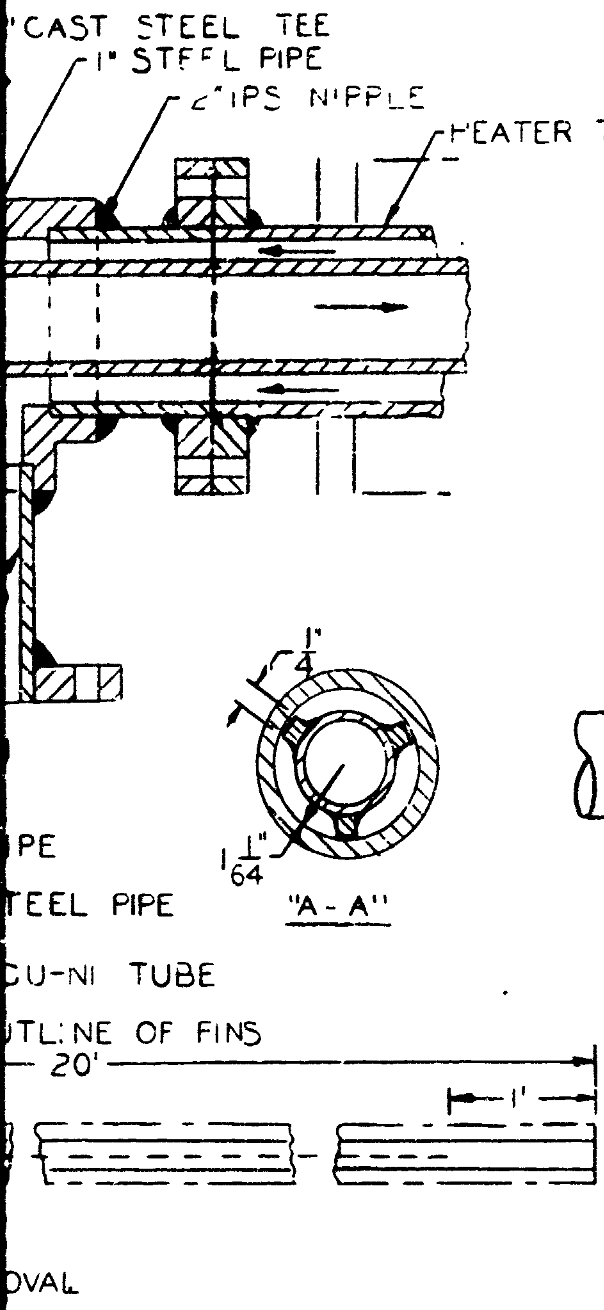
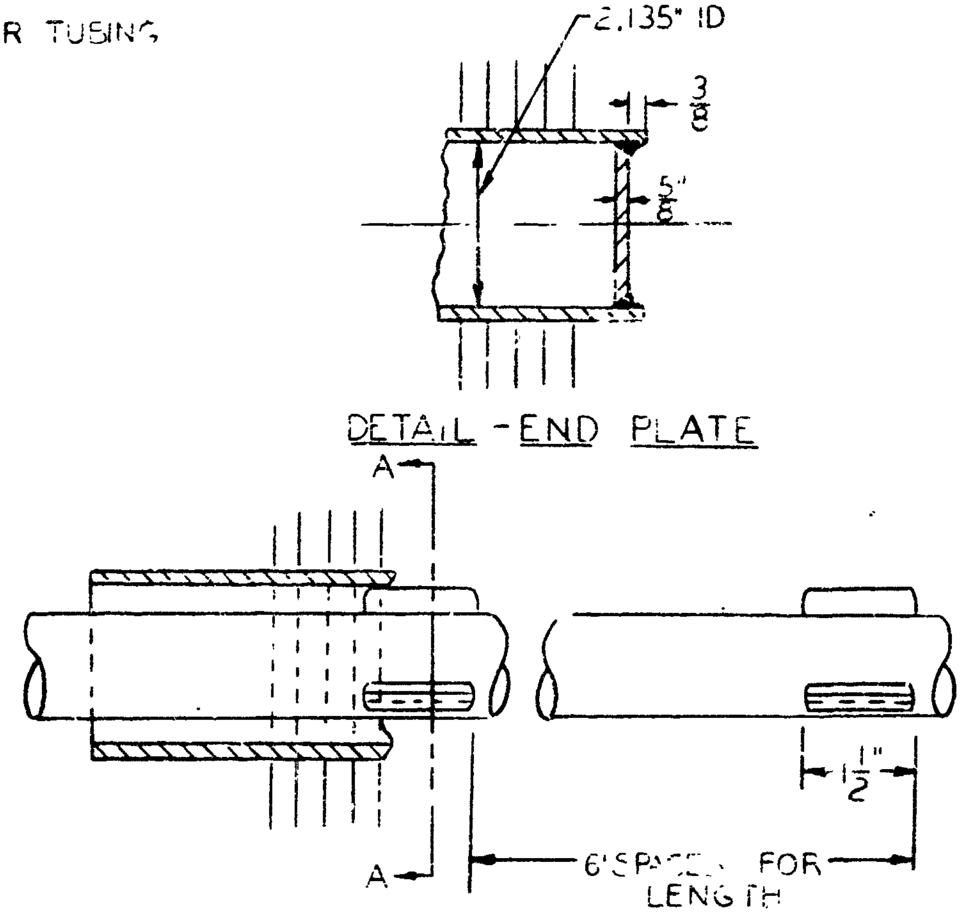


2" CAST STEEL TEE
1" STEEL PIPE
INLET FLANGE
2" IPS NIPPLE
ASSEMBLY OF CONNECTIONS
1/4"
2" IPS PIPE
1 1/64"
"A - A"
1" STEEL PIPE
2" CU-NI TUBE
OUTLINE OF FINS
20'
FLANGE FOR HEATER REMOVAL
DRAIN FLANGE
INLET FLANGE


1

NETI PROJECT B-571

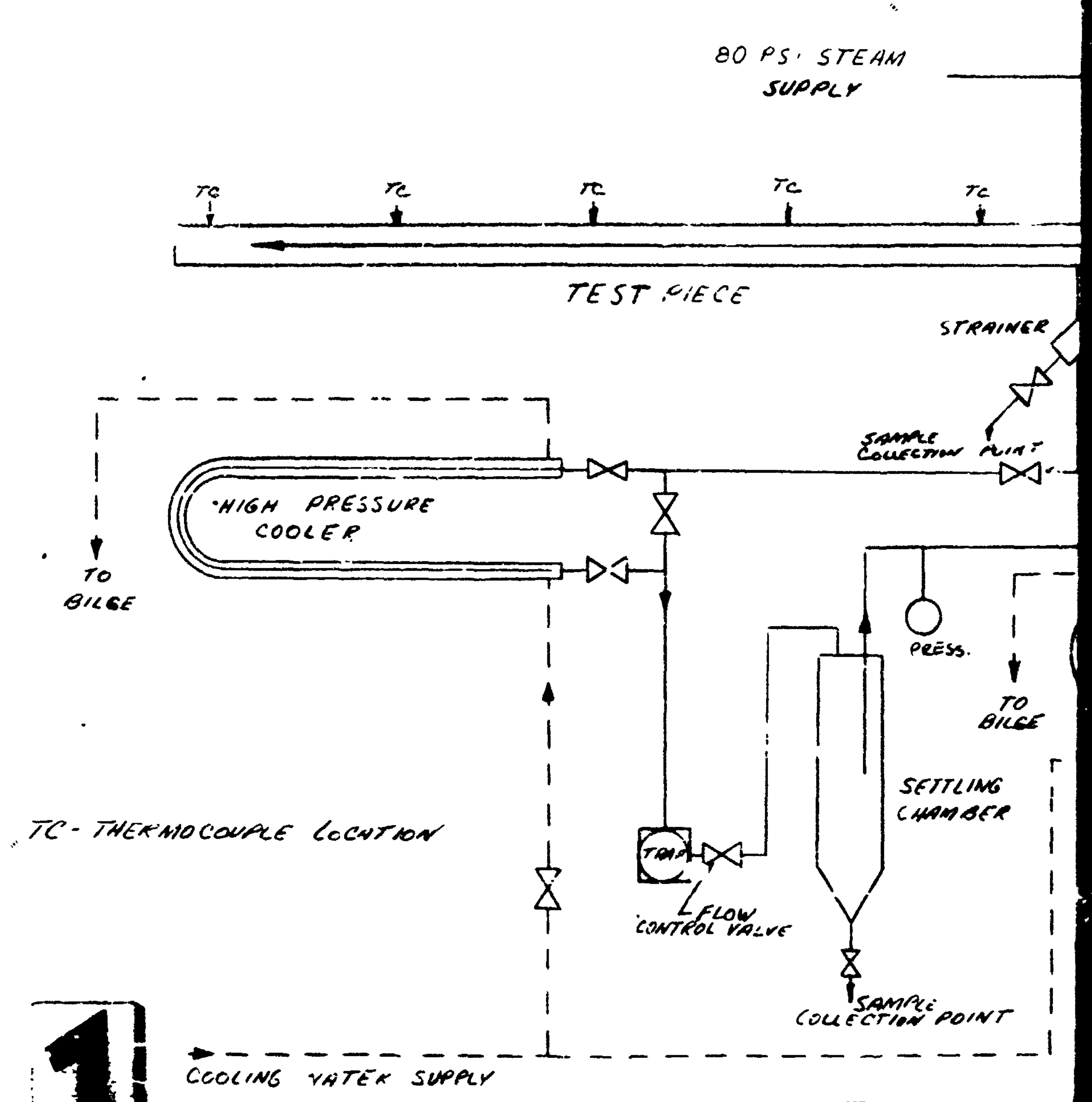



GENERAL ARRANGEMENT AND DETAILS OF TEST PIECE

PLATE I

2


80 PS· STEAM
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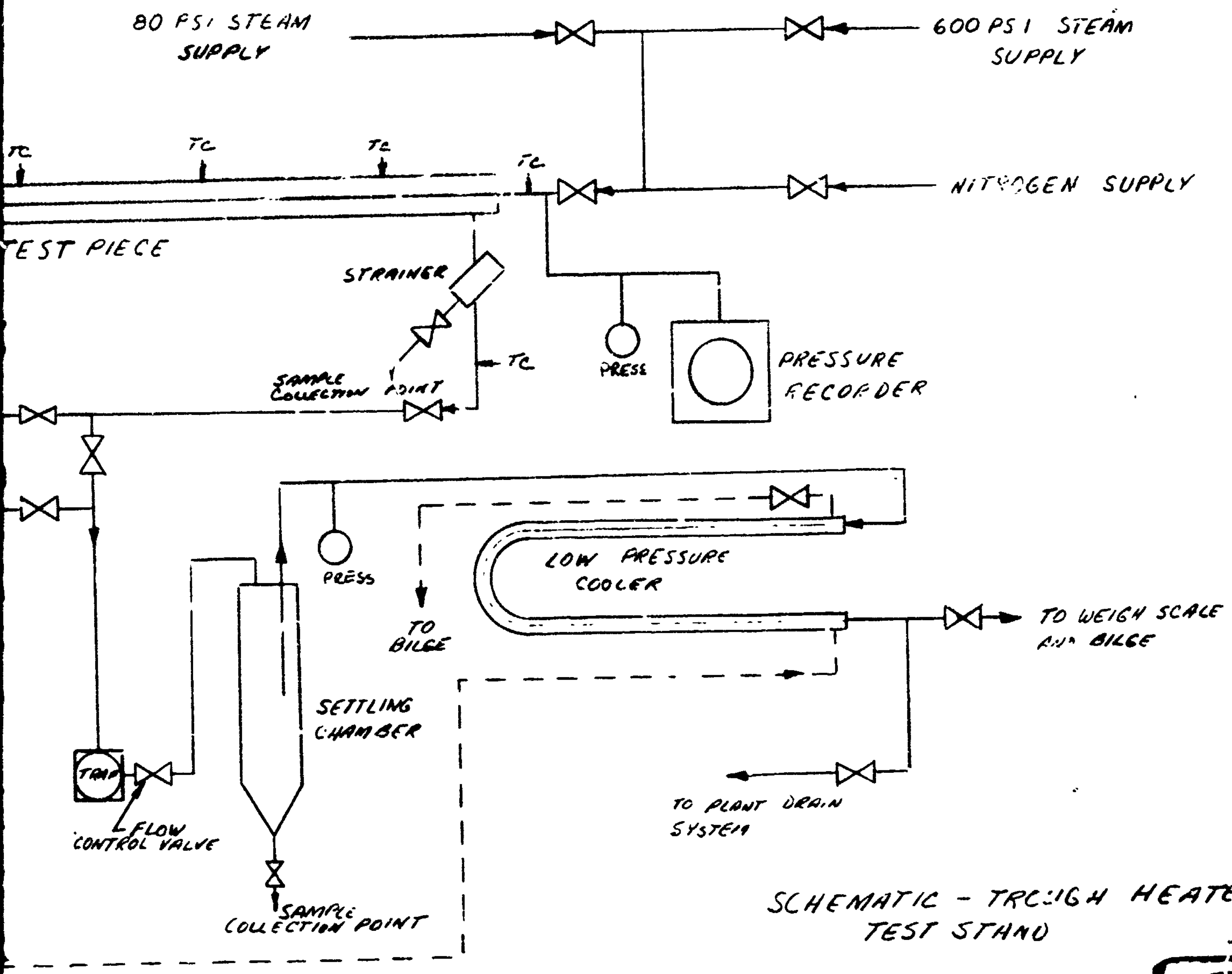


SCHEMATIC - TROUGH HEATER TEST STAND

PLATE 2

| | |
|---|---|
| Naval Boiler and Turbine Laboratory<br>Project No. B-571<br>INVESTIGATION OF 70-30 COPPER-NICKEL CATAPULT TROUGH HEATER TUBING, EVALUATION REPORT, by<br>D. G. Hansen — 10 p., 2 plates<br>24 March 1964 — UNCLASSIFIED<br><br>Aircraft carrier catapult trough heater tubing was tested at the Laboratory to determine the effect of inlet steam temperature on rate of tube wall deterioration. It was found that as long as the catapult trough heater was<br>(over) | I. D.G.Hansen<br>II. Investigation of 70-30 Copper-Nickel Catapult Trough Heater Tubing.<br>III. CVA (Steam Catapults)<br><br>UNCLASSIFIED |


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|---|---|
| Naval Boiler and Turbine Laboratory<br>Porject No. B-57[illegible]<br>INVESTIGATION OF 70-30 COPPER-NICKEL CATAPULT TROUGH HEATER TUBING, EVALUATION REPORT, by<br>D. G. Hansen — 10 p., 2 plates<br>24 March 1964 — UNCLASSIFIED<br><br>Aircraft carrier catapult trough heater tubing was tested at the Laboratory to determine the effect of inlet steam temperature on rate of tube wall deterioration. It was found that as long as the catapult trough heater was<br>(over) | I. D.G.Hansen<br>II. Investigation of 70-30 Copper-Nickel Catapult Trough Heater Tubing.<br>III. CVA(Steam Catapults)<br><br>UNCLASSIFIED |

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